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SYNOPTIC WATER CHEMISTRY MONITORING IN THE ABSAROKA BEARTOOTH WILDERNESS AREA, GALLATIN NATIONAL FOREST AND YELLOWSTONE ECOSYSTEM STUDIES, 1995

JANUARY, 1996

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Executive Summary

In 1995, 14 lakes in the Absaroka Beartooth Wilderness (ABW) were monitored for a wide range of chemistry characteristics as part of the USFS R1 Air Resource Management program in cooperation with Yellowstone Ecosystem Studies (YES). Samples were collected by YES personnel and samples processed by the Rocky Mountain Station Biogeochemistry Lab for base cations and anions. Analysis of the data indicates good internal consistency. Lake chemistry is directly related to parent material. The lakes with least acid neutralizing capacity (ANC) occurred at highest elevations (10,000' and higher), alpine, gneissic granitic watersheds. Although no acidified lakes were identified, 3 lakes with ANC <25ueq/l are considered extremely susceptible to acid deposition. Two potential Phase 3 lakes are tentatively identified for future monitoring. Phase 3 protocols are also discussed. Lake and watershed information needs are discussed which would be used to calibrate each lake to the MAGIC model for future prediction of acid deposition effects on lake chemistry. Recommended monitoring strategies through FY 98 are discussed.

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Literature Cited

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Mark T. Story, Hydrologist, Gallatin National Forest

1) INTRODUCTION

During July-September of 1995, 14 lakes were sampled in the Absaroka Beartooth Wilderness Areas as part of the ongoing Air Resource Management Program (USFS, 1995). This 1995 monitoring was a cooperative effort between the GNF, Yellowstone Ecosystem Studies ("YES") and a followup to a similar efforts between the Gallatin National Forest and The Yellowstone Project in 1993 when 35 lakes were sampled in the ABW (Story, 1993) and 1994 when 19 lakes were sampled (Story, 1995). Yellowstone Ecosystem Studies is a non-profit organization which conducts inventory and monitoring programs to assist the US Forest Service and National Park Service in maintaining long term sustainability of the Greater Yellowstone Ecosystem. Since YES is largely funded through paying volunteers, field data collection efforts are located in scenic GYA environments for which the Beartooth plateau is appropriate.

The primary focus of the (GNF/YES) synoptic monitoring is to provide an overall perspective of the types and variety of chemical processes in ABW in sufficient detail to direct future ABW monitoring efforts and to facilitate tentative selection of Phase 3 lakes (long term benchmark monitoring of a few lakes).

The GNF/YES ABW effort used a sampling scheme and protocols developed by the Forest Service for the Cabinet Mountains (CMW), Selway Bitterroot (SBW), and Anaconda Pintler Wilderness (APW) areas. This consists of 3 phases:

> Phase 1: Reconnaissance of lake watershed conditions. Sampling of pH, alkalinity (field and lab) and lab conductivity to determine lake buffering potential.
>
> Phase 2: Synoptic chemical characterization of selected lakes (about 50% of Phase 1 lakes) for a wide variety of anions and cations. This phase is designed to provide an overall perspective of the types and variety of chemical processes in the lakes, and distribution of lake types and lake sensitive relative to watershed factors.
>
> Phase 3: Intensive chemical monitoring of a few lakes (2-4) to provide a long term benchmark (7-10 years) to evaluate trends in acid deposition and other atmospheric related changes in the lake ecosystems. The Phase 3 data should allow a long term check on lake stability and support calibration of the lake and watershed to acid deposition modeling for PSD purposes.

Specific Objectives of the 1995 monitoring and subsequent analysis include:

1) Identify chemical charactistics for a wide range of anions, cations, and other selected parameters (Phase 2 sampling) in 14 lakes.

2) Re-evaluate several Phase2 lakes from the 1993 and 1994 monitoring which could be suitable for long term benchmark (Phase 3) monitoring of lake chemistry for acid deposition and other atmospheric deposition related changes in lake chemistry and associated biota.

3) Identify Phase 3 protocols (chemical parameters, sampling intensity, duration, and additional factors) for Phase 3 monitoring which is scheduled to start in 1996.

2) METHODS

Lake Selection Criteria

Lakes in the ABW were selected for 1995 monitoring using the following criteria:

* Lakes closest to YES field station in Cooke City. Lakes sampled were primarily in the Clarks Fork River watershed in the Beartooth Mountains. Most of the lakes sampled were within 25 miles of Cooke City.

* Complete high priority lakes not sampled in 1993 and 1994.

* Choose headwater systems over downstream lakes in a lake chain.

* Resample potential Phase 3 lakes identified in 1993 and 1994.

* Give priority to low ANC lakes but sample a few moderately buffered and well buffered systems.

Since Phase 1 data was not available, the ABW lakes were primarily selected to establish a uniform geographical distribution.

Samplers

YES staff and volunteers: Jeff Clark, Greg Clark, Betsy Robinson, Shannon Brooks, David Brooks, Tony Thatcher, Jim Folley, Dawn Boudremux, Elizabeth Clark, Tom Ovenicki

Field Procedures

Lake water samples were collected at a sample depth of about 0.5 meters in the predominately downwind part of the lake, usually by wading. Sample bottles included a 250 ml amber sample bottle, and a 500 to 1000 ml field bottle for onsite chemistry. Three sample duplicates and 2 field blanks were taken. Samples were kept cool in field coolers using frozen gell packs or chemically activated cold compresses and shipped to the labs soon after returning to Cooke City.

Field pH was measured using colorpHfast (EM Science) indicator strips (4-7 range and 6.5 to 10 range). Field alkalinity was titrated using a 100ml sample, 0.2 N H2S04, and brom cresol green-methyl red indicator to the first permanent pink (about pH 4.5).

Photographs were taken of each lake and lake watershed. Field forms were completed with sampling condition, geographic information, geological type, local geological observation, soil vegetation conditions, watershed and snowpack conditions, and other factors which might affect affect water chemistry. Field forms were typed and lab chemistry data, maps, and photographs appended. The field forms are available at the GNF SO and at the Gardiner District.

Laboratory Procedures

The USFS Rocky Mountain Station Biogeochemistry (Fort Collins), under the direction of Louise O'Deen, measured the water chemistry. Parameters and methods include:

pH & alkalinty--Acid Rain Analysis System (ARAS) gran technique; specific conductance--YSI meter; chloride, sulfate, nitrate, ammonia, phosphate, calcium, potassium, sodium, magnesium --liquid ion chromatography; floride--ion specific electrode; aluminum and silica--Lachat flow injection system. Selected magnesium and calcium chromatography values were checked with atomic absorption (Thermo Jarrell Ash 22E). All analyses used QA/QC guidelines and EPA reference standards established in the Handbook of Methods for Acid Deposition Studies (EPA 600/4-87/026 and Standard Methods (APHA, 1989). The data was reviewed for conformance with quality assurance standards prior to use in this study.

3. RESULTS AND DISCUSSION

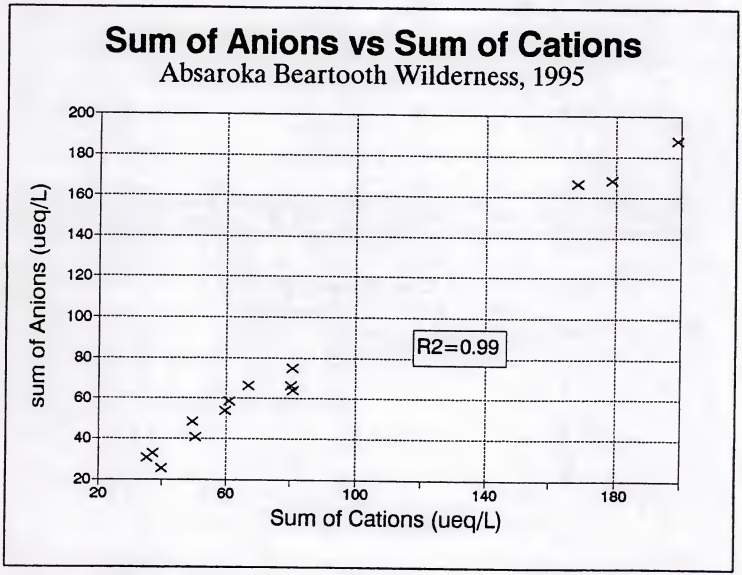
Quality Analysis

Appendix 1 contains synoptic water chemistry data for each of the 15 lakes in mg/L. Appendix 2 provides the synoptic water chemistry data in ueq/L. The field blanks data are well within acceptable limits.

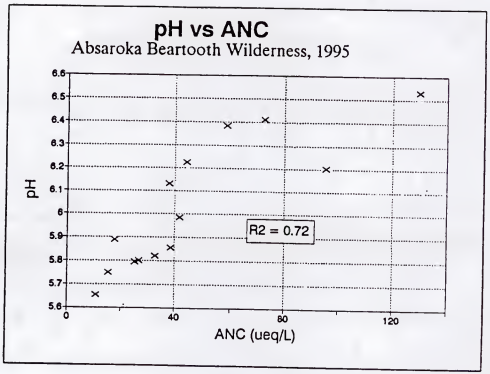
A check of the internal consistency of the data was done by the lab by calculation of the % ion difference between anions and cations (Appendix 2). A slight bias toward higher cations than anions was measured with an average difference of 6.9%. This can be considered within an acceptable range since several minor chemical constituents were not measured (primarily organics).

Lake Chemical Characteristics

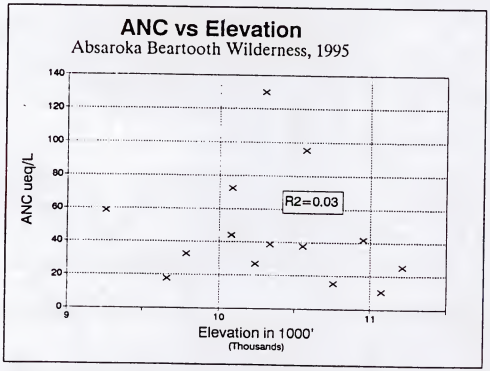
A few lake chemical characteristics (sum of anions vs sum of cations, pH vs ANC, ANC vs elevation) will be shown in figures to illustrate some of the chemistry findings and relationships.



Sums of anions were regressed against the sums of cations for each lake with a correlation coefficient of 0.99. The standard error of Y estimate was 5.47 ueq/L. The close relationship between anions and cations is very similar to results for 1993 and 1994 and supports overall confidence of the internal consistency of the lab data.



Lab pH compared reasonably closely to ANC (R2=0.86). The regression was run using log pH vs log ANC with a standard error of Y estimate of 0.11 ANC units (ueq/L). Since pH is "regulated" by the amount of dissolved bicarbonate (major component of ANC) and the partial pressure of CO2, a close relationship is expected.



In 1995, ANC showed a suprizingly poor correlation with increased elevation. The high standard of error of Y estimate (34.1 ueq/L) did not allow a tight R2 (0.03). This data is shown by lake in Appendix 3. In 1993 and 1994 a closer relationship between ANC and elevation occurred (R2 of 0.38 in 1993 and 0.57 in 1994). However, as in 1994, the 2 lakes with lowest ANC were above 10,700 feet (unnamed T8SR16ES1, T8SR17ESE31).

Geology/Geochemistry and Water Chemistry

Simons (1974) describes the Beartooth Mountains as a block of mainly amphibolite facies, Precambrian granite gneiss, amphibolite, and subordinate metasedimentary rock intruded by many Precambrian mafic dikes. The Precambrian rocks are also intruded by numerous silicic dikes and plugs of Tertiary and possibly Cretaceous age and, in the western edge of the Beartooth uplift, overlain by small patches of Tertiary volcanic rocks.

Ramsey (1978) describes the parent material in all of the lakes sampled as Precambrian crystalline, metamorphic and belt series with granite, gneiss, achist, amphibolite, pegmatite, and basic dike rocks. Hammarstrom (1993) provides more detailed information on the Beartooth uplift and geochemically seperated the ABW in to 4 areas as shown in the map below.

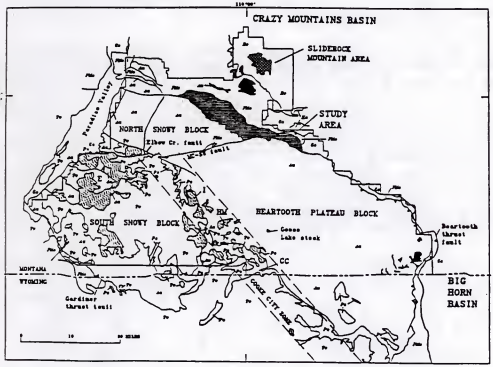


Figure B1.--Generalized geologic map for the Beartooth uplift and vicinity, Montana and Wyoming.

All of the lakes sampled in 1995 were in the Beartooth plateau block. Dominant minerals in all of the lakes include quartz, biotite, hornblende, and feldspars. Pegmatite dikes occur through much of the gneiss terrain and consist of quartz, pink microcline, white plagioclase, biotite, and muscovite (Simmons et.al., 1979). Lake wa chemistry compares well to the mineral resource investigations. Geochemical analysis of the grantic gneiss indicates a range of 66 to 72% SiO_2. Weathering of the quartz gneiss dominated minerology produces average lake chemistry which is similar to the SBW (granitic dominated minerals) but more dilute than average lake chemistry in the APW or CMW 1992 results (Table 1).

Silica levels in the ABW (1993 data) were not as high as lakes in the SBW but the base cations Ca, Mg, and K are higher in the ABW. Average ANC for the 93/94/95 lakes monitored in the ABW is 67.9 ueq/L compared to 51.8 for the SBW (1992). The ABW has a wider range in rock and mineral types than the more silica dominated intrusive granitic batholith of the SBW.

Lakes in the Beartooth plateau had generally similar chemistry characteristics with the primary differences attributable to elevation and the degree of soil and vegetation development. The highest elevation lakes sampled (unnamed T9SR16ES1, T8SR17ESWS31, T8SR17SES31, Big Red Rock, and Stepping Stone) are all above timberline with very little soil development. These lakes had ANC < 38 ueq/L, low pH (5.5-6.0) and low conductivity (4.9-7.8 uS/cm). In 1994 and 1995 lower elevation lakes sampled in the Beartooth Plateau (Marmot, Spogen, Throop, Granite) had much higher ANC's (77 to 99 ueq/L), conductivity (8-16 ueq/L), and slightly higher pH (6.6 to 6.7). The amount of dissolved minerals in evidently enriched by vegetation and deeper soil development in the lower montane lakes.

Average ANC in 1994 in the ABW was 46.2 ueq/L which is less than the average ANC of 71.2 ueq/L in 1993 and 59.7 in 1994. Anion and cation composition is similar in both 1993, 1994, and 1995 data sets. However the 1995 sampling focused on high elevation, low ANC lakes.

The lowest ANC lake measured, unnamed T8SR17ESWS31 (10.7 ueq/L in 1994, 10.8 ueq/L in 1995) is located at the head of a drainage in a small basin with essentially no soil development, no trees or krumholtz, and limited opportunity for base cation mobilization. The ANC of 10.7 ueq/L, (about 0.5 ppm or mg/L of buffering) makes this lake highly sensitive to acidification from atmospheric deposition. This lake is the 2nd most dilute lake identified in USFS Region 1 and has a lower ANC than any measured lake in the SBW and second only to upper Libby Lake in the CMW which has measured ANC from 5-7 ueq/L. However unnamed T8SR17ESWS31 is not readily accessible for Phase 3 monitoring.

Table 1. Absaroka Beartooth 1993/1994/1995 Lakes
Average Values and Standard Deviations

MG/L

attribute	pH	Conduct.	Ca	Mg	Na	K	NH4	Cl	NO3	SO4	P
average ABW (93)	6.6	10.3	1.2	0.3	0.4	0.4	0.0	0.3	0.2	1.0	0.0
stnd dev ABW	0.2	5.9	0.8	0.2	0.2	0.3	0.0	0.3	0.2	0.8	0.0
average ABW (94)	6.5	11.6	0.7	0.2	0.7	0.6	0.1	0.8	0.4	0.7	0.0
stnd dev ABW	0.2	6.6	0.4	0.1	0.5	0.5	0.0	1.0	0.4	0.5	0.0
average ABW (95)	6.0	8.5	0.7	0.2	0.4	0.3	0.1	0.3	0.3	0.8	0.0
stnd dev ABW	0.3	4.4	0.5	0.2	0.3	0.3	0.1	0.3	0.3	1.0	0.0
average ABW (93/94)	6.6	11.0	1.0	0.3	0.5	0.4	0.1	0.5	0.2	0.9	0.0
stnd dev ABW	0.2	6.2	0.7	0.2	0.4	0.4	0.0	0.7	0.3	0.8	0.0
average ABW (93/94/95)	6.4	10.5	1.0	0.3	0.5	0.4	0.1	0.5	0.3	0.9	0.0
stnd dev ABW	0.3	6.0	0.7	0.2	0.4	0.4	0.1	0.6	0.3	0.8	0.0

UEQ/L

attribute	CA	MG	NA	K	NH4	CL	NO3	SO4	ANIONS	CATIONS	ANC
average ABW (93)	57.6	25.9	18.8	9.3	1.4	9.8	2.9	20.1	104.0	113.3	71.2
stnd dev ABW	38.4	16.6	10.2	8.2	1.5	9.3	3.6	17.0	65.2	65.0	51.1
average ABW (94)	36.7	18.6	29.0	15.1	4.0	22.1	6.0	14.8	102.6	103.9	59.7
stnd dev ABW	15.4	9.5	22.9	13.2	2.3	27.0	5.7	11.1	58.1	58.1	32.2
average ABW (95)	35.9	18.2	16.2	8.4	4.9	9.0	4.9	17.5	77.5	52.5	46.2
stnd dev ABW	35.0	13.2	12.0	7.4	7.0	9.1	4.2	20.2	52.5	53.2	32.1
average ABW (93/94)	50.5	23.5	22.7	11.5	2.4	14.3	4.0	18.4	104.6	110.9	67.9
stnd dev ABW	34.0	15.0	16.6	10.7	2.2	18.8	4.7	15.5	63.0	62.3	45.5
average ABW (93/94/95)	48.4	22.9	21.4	10.8	2.9	13.2	4.1	18.6	100.2	106.8	64.4
stnd dev ABW	33.5	15.3	15.8	10.1	3.8	17.2	4.6	16.8	62.5	62.0	44.4

Acid Deposition Sensitivity

Many of the lakes sampled in the ABW are sensitive to acidification from atmospheric deposition but no lakes are presently acidic.

The Stanford et.al. (1993) report on the R1 Air Quality Screening Workshop--Aquatic Section includes screening criteria for lake sensitivity developed by a workgroup of scientists and managers. The criteria for the aquatic screening parameters measured in the 1991 sampling include:

screening parameters	screening criteria
ANC	>200 ueq/L not sensitive to acidic inputs
	100-200 ueq/L minimal if any sensitivity
	<25 ueq/L red flag (highly sensitive)
pH	7.3 minimal if any sensitivity
	6.4-7.3 potential sensitivity <6.0 concern for pH depression
conductivity	>20 uS/cm minimal if any sensitivity 10-20 uS/cm potential sensitivity
	<10 uS/cm dilute, potentially responsive
anions	total S04 + N03 (ueq/L) > 10% of total base
	cations may indicate the influence of
	acidic inputs
total phosphorous	<10 ug/L sensitive
	<5 ug/L indicates extremely responsive
aluminum	<50 ug/L (LAC)

Three ABW lakes (21%) measured in 1995 have ANC less than 25 ueq/L. Several lakes have pH less than 6. A total of 13 lakes (78%), have less than 10 uS/cm of conductivity. All lakes measured had less than 5 ug/L of phosphorous (all were below phosphorous detection limits) and less than 50 ug/L of aluminum. The lab detection limits for phosphorous (0.01 ppm) were not sufficiently precise for screening criteria use at this time.

The most acid deposition sensitive lakes measured in 1995 include unnamed T9S R16E S31, T8SR17ESWS31, Twin Island, and T8SR15ENES26. Since 1 ppm of alkalinity = 20 ueq/L of ANC, all of these lakes have less

than or slightly above only 1 part per million of alkalinity buffering.

In higher ANC lakes, the weathering of primary minerals (which could be accelerated with acid deposition) results in solution of calcium and magnesium and a balanced amount of bicarbonate. In lake systems which have carbonate bearing strata, increased acid deposition would be largely neutralized by increased weathering which releases base cations into solution. Carbonate bearing strata occur only on the fringes of the ABW. The conductivity screening criteria is not consistent with the ANC criteria for dilute lakes. A revised R1 screening criteria of less than 5 uS/cm would provide a more consistent tie to the ANC screening criteria.

The anion criteria of total sulfate + nitrate <10% of base cations was exceeded for all lakes (Appendix 3). The SO4 + NO3/base cation ratio in the 1995 ABW data averages 0.26 ranging from 0.12 at Stepping Stone lake to 0.46 for Zimmer lake. The highest elevation low ANC lakes in 93-95 had the highest ratios which appear to be due primarily to low base cations. Actual sulfate concentration is less in the low ratio lakes but ratios are elevated by the low base cations. Assuming most of the sulfate is from geologic and not atmospheric sources, the 0.10 ratio criteria is not appropriate for the ABW. A similar finding occurred in the 1992 Phase 2 monitoring in the SBW, CMW, and APW and the ABW in 1993 and 1994. The SO4 + NO3/base cation ratios would be more useful to compare time trends for individual lakes monitored over several years.

For lake systems not experiencing acid deposition, the "standard composition" of lake water includes calcium and magnesium as the dominant cations and bicarbonate as the dominant anions (Rodhe, 1949). This generality applies to all of the 1993 ABW lakes except for Goose lake (where sulfate is the dominant anion) and all ABW lakes sampled in 1993, 1994, and 1995. Although none of the ABW lakes appear to be degraded under current acid deposition levels, many of the lakes are extremely susceptible to damage from future degradation of air quality as relatively small additions of sulfuric or nitric acid deposition could cause the lakes to become acidic. The most sensitive ABW lakes have considerably less buffering capacity than many of the Adirondack lakes which have become acidified.

4. PHASE 3 LAKES

Selection Criteria

Six criteria were used to tentatively identify 2 lakes for long term benchmark (Phase 3) monitoring including:

1) Low ANC and conductivity

2) Lakes should have representative chemistry for low ANC lakes in the wilderness area, and representative depth and morphometry for all lakes.

3) Relatively low dissolved sulfate from watershed sources.

4) Reasonable trail access

5) No obvious man caused effects such as impoundments and fluxuating water levels, or historical mining activities in the watershed

6) The lake should be upstream of all other lakes in the drainage, and with a non-complex watershed to facilitate future lake/watershed chemistry modeling.

Potential Phase 3 Lakes

Stepping Stone and Twin Island Lakes are selected as Phase 3 lakes for the ABW. Primary reasons for selection were the low 1995 ANC , relatively low NO3 + SO4/base cation ratios, and are reasonably accessibility via the Russell Lake trail.The lowest ANC lakes measured in 1993, 1994, and 1995 such as T8SR15ENES26 AND T8SR17ESWS31, are too inaccessible for routine Phase 3 monitoring.

Phase 3 Parameters

Phase 3 monitoring should be designed to provide a long term benchmark to evaluate trends in acid deposition and other atmospheric related changes in the lake ecosystems. The primary focus is on chemistry data but supportive physical characterization and documentation of biological organisms is recommended. The Phase 3 data should allow a long term check on the lake ecological stability and support a specific calibration of each Phase 3 lake and watershed to the MAGIC model (Eilers et.al., 1991). The MAGIC model can be used to estimate chemical effects on lakes from proposed upwind emission increases as part of the PSD permit application and analysis process.

Phase 3 recommended methods and parameters include:

1) Collect samples in a raft in the middle of each lake

2) Run a temperature profile

3) Measure "Phase 2" chemical parameters (pH, conductivity, Ca, Mg, Na, K, NH4+, F, NO3, SO4, ANC, SiO2, P, Al, gran alkalinity, calculate ANC). Use better precision for P than in 93/94/95. Include duplicates and field blanks.

4) Total Kjeldahl nitrogen (organic nitrogen), organic carbon (dissolved or total), and summer measurement of trichromatic chlorophyl A.

5) Periodic measurements (at least 2X in the first 7 years) of phytoplankton. This could consist of a 500 ml sample and a qualitative identification of major photoplankton (mainly diatoms) species.

6) Sample frequency should be twice yearly, including early as possible (early July) and the fall overturn period (late September).

7) Duration of sampling should be a minimum of 5 years until a clear trend is established.

8) Data should be plotted each year and laboratory results evaluated to insure lab reporting consistency and for statistical trend analysis.

Watershed and Lake Chemistry Modeling

The Phase 3 lake data can be linked directly into the R1 Forest Service air regulatory process cabability by calibrating each Phase 3 lake to the MAGIC model (Eilers et.al., 1991). The MAGIC (Model of Acidification of Groundwater in Catchments) was used in the R1 1991 Screening Workshop (Stanford et.al., 1993) for a tentative assessment of acid deposition sensitivity of 12 R1 lakes in the Absaroka Beartooth, Selway Bitterroot, and Bob Marshall Wilderness Areas. The MAGIC model calibration consists of adjusting model coefficients

through an optimization process using watershed factors, soil information, atmospheric deposition chemistry, and lake chemistry. Once a lake is calibrated to its watershed and atmospheric deposition input factors, lake chemistry response can be hindcast and forecast to allow input of potential changes in atmospheric deposition and prediction of associated changes in lake chemistry. This is potentially a very useful tool in (Prevention of Significant Deterioriation) PSD applications. For example, emissions from a proposed mine, smelter, or industrial facility upwind of the ABW could be evaluated with a dispersion model to estimate changes in the atmospheric deposition loading rates at the Phase 3 lake. This "changed" deposition would then be input to the MAGIC model to estimate changes in the water chemistry. These potential changes would then be compared to the Screening Criteria discused in the Acid Deposition Sensitivity part of this report (Stanford et.al., 1993), and a decision made if an adverse impact determination is appropriate. Information which would be needed for a specific MAGIC calibration of each Phase 3 lake includes:

1) at least 2 years of Phase 3 lake chemistry data

2) Soil "survey" of soil depth, cation exchange capacity (Ca, Mg, Na, K), base saturation, soil pH, bulk density, and porosity for each of the major soil types in the lake watershed above the lakes. Soil in the Stepping Stone lake watershed is very limited.

3) Map of rock outcrops, permanent snow fields, and vegetation in the lake watershed

4) characterization of dominant rock minerals

5) plot of stream network upstream of the lake

6) lake depth profile

7) measurements of discharge at inlet(s) and outlet through a range of discharges, including the peak of snowmelt runoff

8) pH, ANC and sulfate in inflowing streams

9) average annual precipitation

10) charactization of deposition chemistry. This could be done by collecting spring snow cores and comparing with the Tower Junction NADP site in Yellowstone National Park.

The MAGIC model calibration is not useful for lakes higher that 50 ueq/l of ANC since higher ANC lakes would not likely be acidified in any reasonably forseeable acid deposition scenario.

Future ABW Lake Monitoring

Appendix 4 (which is taken from the R1 Air Resources Monitoring Plan from May 1995) outlines the anticipated lake monitoring which would be necessary to allow a MAGIC model calibration of 4 ABW lakes in FY 98. All of the 1994 and 1995 work is completed. The FY96 sampling should be focused on monitoring Twin Island and Stepping Stone, the Phase 3 lakes. In the Appendix 4 schedule, the 2 phase 3 lakes would be sampled in FY96 and FY97 with the MAGIC model calibration in FY98. This monitoring will be included as an integral part of the ABW Wilderness Plan update.

These Phase 3 and MAGIC model calibration efforts are coordinated with similar efforts in the CMW and SBW to establish a USFS R1 geographic network of acid deposition sites. This 3 site network would allow the Forest Service to participate in the air quality regulatory process in a scientific and substantial manner. MAGIC model analysis of future PSD applications which have potential to adversely affect ABW lake chemistry will allow the Forest Service to identify potential adverse effects (adidification of lake chemistry). This would lead to recommend changes in the proposal, usually reduced emissions through more intensive air pollution control technology. This modeling capability would provide a major tool in allowing the Forest Service to maintain long term ecosystem integrity of the ABW lakes.

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Appendix 1. Absaroka Beartooth Wilderness 1995, GNF/YES, Displayed in mg/L

		uS/cm	------	----------	----------	----------	--MG/L-	----------	----------	----------	-------	UEQ/L	MG/L
LAKE NAME	pH	Conduct.	Ca	Mg	Na	K	NH4	F	Cl	NO3	SO4	ANC	PO4
BIG RED ROCK	6.131	5.516	0.668	0.202	0.139	0.149	0.001	0.000	0.126	0.429	0.498	37.700	0.000
EAST RED ROCK	6.204	16.331	0.902	0.273	0.959	1.193	0.508	0.000	1.283	0.717	1.114	95.300	0.000
ELAINE	6.385	7.979	0.769	0.304	0.290	0.132	0.012	0.000	0.078	0.000	0.697	58.400	0.000
ELPESTRINE	5.985	8.021	0.457	0.193	0.314	0.298	0.107	0.000	0.300	0.527	0.368	41.800	0.000
FIZZLE	6.225	6.945	0.827	0.269	0.251	0.198	0.007	0.000	0.110	0.170	0.685	44.100	0.000
LOOKING GLASS	6.531	17.024	2.052	0.652	0.647	0.476	0.040	0.000	0.517	0.000	2.071	130.000	0.000
SODALITE	5.821	6.298	0.478	0.110	0.227	0.174	0.015	0.000	0.134	0.068	0.520	32.700	0.000
STEPPING STONE	5.857	7.827	0.401	0.105	0.644	0.535	0.152	0.000	0.649	0.156	0.341	38.400	0.000
T8SR15ENES26	5.801	5.214	0.380	0.129	0.227	0.215	0.068	0.000	0.165	0.232	0.277	26.800	0.000
T8SR16ES1	5.750	4.939	0.352	0.108	0.104	0.115	0.022	0.000	0.086	0.613	0.265	15.300	0.000
T8SR173SWS31	5.654	4.747	0.171	0.065	0.180	0.182	0.118	0.000	0.190	0.638	0.212	10.800	0.000
T8SR17ESES31	5.795	6.555	0.479	0.117	0.308	0.281	0.070	0.000	0.351	0.588	0.457	25.200	0.000
TWIN ISLAND	5.889	4.509	0.515	0.092	0.066	0.040	0.000	0.000	0.040	0.000	0.325	17.700	0.000
ZIMMER LAKE	6.413	16.333	1.614	0.471	0.860	0.618	0.108	0.000	0.451	0.102	3.902	72.400	0.000
average	6.032	8.446	0.719	0.221	0.373	0.329	0.088	0.000	0.320	0.303	0.838	46.186	0.000
standard deviation	0.271	4.389	0.500	0.160	0.275	0.290	0.126	0.000	0.321	0.259	0.969	32.122	0.000

Appendix 2. Absaroka Beartooth Wilderness 1995, GNF/YES, Displayed in ueq/L

	UEQ/L								
	CA	MG	NA	K	NH4	CL	NO3	SO4	ANC
TWIN ISLAND	25.70	7.57	2.87	1.02	0.00	1.14	0.00	6.76	17.70
SODALITE	23.85	9.05	9.87	4.45	0.83	3.79	1.09	10.82	32.70
STEPPING STONE	20.01	8.64	28.01	13.68	8.43	18.32	2.52	7.09	38.40
FIZZLE	41.27	22.14	10.92	5.06	0.39	3.09	2.74	14.27	44.10
T8SR15ENES26	18.96	10.62	9.87	5.50	3.77	4.65	3.74	5.78	26.80
T8SR17ESES31	23.90	9.63	13.40	7.19	3.88	9.89	9.49	9.50	25.20
ELAINE	38.37	25.02	12.61	3.38	0.67	2.19	0.00	14.50	58.40
T8SR16ES1	17.56	8.89	4.52	2.94	1.22	2.43	9.89	5.52	15.30
T8SR173SWS31	8.53	5.35	7.83	4.65	6.54	5.37	10.28	4.42	10.80
BIG RED ROCK	33.33	16.62	6.05	3.81	0.06	3.56	6.91	10.37	37.70
ELPESTRINE	22.80	15.88	13.66	7.62	5.93	8.45	8.50	7.65	41.80
EAST RED ROCK	45.01	22.46	41.71	30.51	28.16	36.19	11.56	23.20	95.30
ZIMMER	80.54	38.77	37.39	15.81	6.01	12.72	1.64	81.24	72.40
LOOKING GLASS	102.400	53.65	28.14	12.17	2.22	14.58	0.00	43.12	130.00
average	35.88	18.16	16.21	8.41	4.86	9.03	4.88	17.45	46.19
standard deviation	34.97	13.20	11.97	7.41	6.99	9.05	4.18	20.18	32.12

Appendix 3. Absaroka Beartooth Wilderness, 1995

Sorted by ANC & Sulfate + Nitrate to Base Cation Ratios

Lake	Elevation	ANC ueq/L	SO4+NO3/Base Cations
ELAINE	9256	58.40	0.18
TWIN ISLAND	9660	17.70	0.17
SODALITE	9790	32.70	0.24
FIZZLE	10080	44.10	0.21
ZIMMER	10085	72.40	0.46
T8SR15ENES26	10230	26.80	0.19
LOOKING GLA	10300	130.00	0.22
STEPPING STO	10330	38.40	0.12
BIG RED ROCK	10555	37.70	0.28
EAST RED ROC	10570	95.30	0.21
T8SR16ES1	10754	15.30	0.42
ELPESTRINE	10956	41.80	0.24
T8SR17ESWS31	11075	10.80	0.42
T8SR17ESES31	11215	25.20	0.32

APPENDIX 4 ANNUAL COST PER FOREST TO IMPLEMENT ARM MONITORING

Forest	FY94	FY95	FY96	FY97	FY98	FY99
Lolo			$2,000 Lichens MMW			
Lewis & Clark				$1,000 SGW AQRV Plan		
Gallatin	$4,000 Phase 1 mtg of 20 ABW lakes $3,000 Phase 2 mtg of 10 ABW lakes (funded by YES)	$4,000 Phase 2 mtg of 20 lks (funded by Yel Pjct)	$6,000 Phase 3 mtg of 2 lakes	$6,000 Phase 3 mtg of 2 lakes	$18,000 MAGIC model calib of 2 ABW lakes	
				$5,000 ABW RVAAP/WIS Plan	Implement ABW RVAAP/WIS Plan	Implement RVAAP/WIS Plan

APW-Anaconda Pintler Wilderness
BMW-Bob Marshall Wilderness
CMW-Cabinet Mountains Wilderness
GMW-Gates of the Mountains Wilderness
MMW-Mission Mountains Wilderness
SBW-Selway Bitterroot Wilderness
HCW-Hell's Canyon Wilderness
ABW-Absaroka Beartooth Wilderness